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ARITHMETICAL STRUCTURE OF THE PARALLEL TYPE WITH TRANSISTORS' (semi conductors') INSTRUMENTS

Moscow - 1957

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F O R E W O R D

The objective of this paper is to design and to evaluate the elementary triode transistor circuits possessing, if possible, more of high speed characteristics.

Along with the above, the circuits are to satisfy all the requirements of stability, particularly of lower sensitivity to the variations of input voltage, etc., which are peculiar to the circuits of this nature. A dynamic principle of work was used as the basis of development of circuits, allowing the construction of the most simple and high frequency circuits. Point contact triodes were used, permitting operation at higher frequencies, instead of the existing junction-type triodes.

I ELEMENTARY CIRCUITS

1. Dynamic Trigger. - The action of the dynamic trigger is based on the characteristic of the capaciter C to hold the charge for a given period of time. (Fig. 1) Essentially this circuit may be viewed as a coincidence rectifier with a fixed frequency repetition* being applied to one of the inputs, synchronising the action of the circuit. The voltage of the capaciter C is applied to the second input.

When the capaciter C is discharging the rectifier is closed, consequently the pulse " ΓM " will not pass (point 0). When the capaciter charges the rectifier opens and a series of pulses identical with the pulse " ΓM " appear at the output.

* In the future we will refer to it as "main pulse" (ΓM)

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OUTPUT

Fig. 1. Block Diagram of the Dynamic Trigger

As can be seen from the principal circuit (Fig. 2) the triode in the circuit is grounded, this being the most logical method of power amplification when using the point contact triodes. The triode is closed by the positive bias of the base "$E_б$". The positive pulse "$U_{вх}$" is passed thru the transformer "Tp_1" to the triode emitter. The basic lead C_2, which is parallel with the large discharge resister R_2, is fed thru the secondary of Tp_1 into the base emitter circuit.

OUTPUT 1

OUTPUT 2

Fig. 2. Principal Diagram of the Trigger

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In order to adjust the trigger at point "1" the positive pulse "adjustment at point 1" (Y"1") is fed into the capacitor C_2 thru the diode $Д_2$ which charges the capacitor to the potential $U_{c2}=E_б$. At this time the pulse "Г И" is able to pass thru the triode. At the end of the pulse Y"1" the capacitor C_2 begins to discharge at fixed time determined by the RC.

In order to keep this trigger functioning at point 1 indefinitely it is necessary to recharge the C_2 periodically with the positive pulses which are fed into the capacitor C_2 from the secondary of the Tp_2 thru the diode $Д_3$.

The adjustment of the trigger at point "0" is accomplished with the negative pulse fed into the capacitor C_2 thru the diode $Д_2$. The time constant of discharge, in this case, is small. In order for the diode $Д_2$ to cut-off at the maximum capacitor voltage it is necessary to place on the diode's cathode a positive cut-off bias $E_0 > U_{c2}$ max. To decrease the voltage U_{c2} min the circuit provides an additional resistor R_2= 100 KOhms.

The value of the capacitor C_2 is equal to 250 $\mu\mu$f. To determine this value it is necessary to remember that from the point of view of the discharge time constant it should be relatively large. The increase of the time constant at the expense of the increased resistance is undesirable inasmuch the circuit's dependency on the shifts of the diodes and triodes increases, and besides the capacitor's output power (to which several coincidence rectifiers are coupled) decreases.

Pulse transformers are used to assure the quality of coupling at various stages. The coil of the transformer is wound on a double ferrocart 1000 core, 4 x 7 мм. The primary, coupled to the collector, consists of 100

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turns (Tp_2). The number of turns on the secondary is determined by the load at which the triode operates; in the circuit under consideration the secondary, in the regeneration stage, consists of 40 turns, the output coil of 20 turns.

To stabilize the dark current of the collector a resistance R_k, shunted with the capacitor C_3, is incorporated into collector's circuit immediately after the transformer.

A small circuit R_1, C_1 is incorporated between the basic capacitor C_2 and the transformer Tp_1 to improve the wave shape of the output pulse.

To determine the so called "safety margin" or "base margin," which characterizes the functioning of the trigger, it is necessary to know the technical characteristics of the dynamic trigger. To do this the pulse "ΓM" is fed into the circuit of the dynamic trigger, the base voltage changes and the two voltage values, one of which corresponds to the flip-flop trigger circuit at point "1" ($U\delta_1$), the other the flip-flop trigger circuit at point "0") ($U\delta_0$), are being fixed. Always, of course, $U\delta_0 > U\delta_1$. The difference between $U\delta_0$ and $U\delta_1$ is called the <u>base margin</u> of the trigger. During absence of the load the base margin should not be less than 3v.

The dynamic trigger has following technical characteristics:

a. Normally, the trigger circuit operates with the pulse repetition frequency in the band width 150-1200 Kc. (Fig. 3) On this graph as well as in Figures 4 & 5 are the curves of three various triodes/type 6Zh, taken from the one set. The frequency of trigger pulse in the circuit with the calculating output may be changing from zero to the frequency of the pulse "ΓM".

b. Parameters of output pulse: pulse ΓM - repetition frequency 500Kc, amplitude 2v, duration 0.3μ sec; impulses Y"1" and Y"0" amplitude 7-8v

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and duration .5 μ sec. Amplitude of pulse f_M should be maintained at ± 25%.

A very rigid requirement is set forth for the relation of the amplitude and duration of the pulse f_M since because of the inferior wave forming characteristic of the trigger the amplitude and duration the determine output wave shape.

In view of the low input impedance the pulse generator should be sufficiently strong.

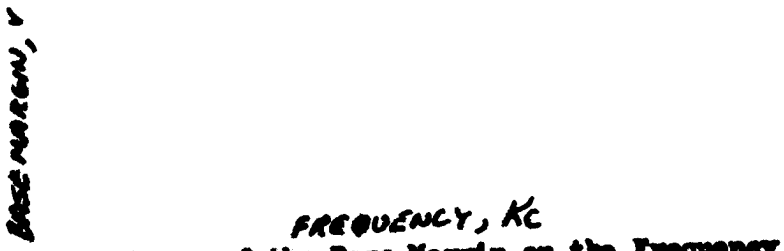

Fig. 3. Dependence of the Base Margin on the Frequency

c. The time delay for the pulse to pass thru the circuit is 0.1-0.15 μsec. Duration of the output pulse is .5-.6 μsec.

d. The relationship of the base margin trigger, coupled to the secondary of the output transformer with the transforming coefficient 5:1, is shown in Fig. 4. Fig. 5 shows the relation of the base margin to the load capacity (with the same transformer).

Fig. 4.

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Base Margin (v)

Fig. 5. Lead Capacity ($\mu\mu f$)

d. The circuit is not critical towards the change of the feeding voltage. During the absence of leading, the base margin of the circuit is 3-5 volts. At the time of highest possible lead, change of the basic voltage is allowed in the limits of plus or minus 10 percent.

e. For investigation of the questions of interchangeability of triodes in the same trigger, we tested three types of triodes; C1E, C1D and C2B, selecting fifty each. A base margin greater than 3 volts was exhibited in 90% of type C1E, 60% of type C1D and 86% of type C2B.

In Figure 6, the work of the dynamic trigger is shown on oscillographs.

Fig. 6. TRIGGER OSCILLOGRAMS

a. FH, 500 KC, 2 V. б. OUTPUT IMPULSES, 5 V.
в. VOLTAGE ON BASIC CAPACITY, AMPLITUDE DROP 4 V.

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2. Impulse Syncroniser. The circuit of the impulse syncroniser (Fig. 7) differs from the circuit of the dynamic trigger only in that in place of positive impulses of regeneration on the basic capacity, negative impulses are found in the output. These syncronizing impulses which appear at the circuit input at an arbitrary moment of time, charge the capacity and set the circuit in position "1." The first impulse ΓU, passing through the circuit after it is set in position "1," enters the capacity through diode $Д_2$, discharges it and sets the circuit in position "0." At this time the impulse appears in the circuit output, coincident with the impulses ΓU, if circuit delay is to be disregarded.

The technical characteristic of the syncroniser circuit are similar to the circuit of the dynamic trigger.

Fig. 7.

3. Impulse shaping network. The impulse shaper is intended to amplify power and to reestablish the standard form of impulses, which are weakened and disfigured by the preceeding networks. The operation of the circuit is based on the utilization of the negative part of the input volt-amperage characteristics which are possessed by point triodes during presence of resistance in the base network. Shown in Figure 8 is the shaping network.

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Fig. 8.

The peculiarity of the presented circuit in comparison with circuits described in reference 5, is the fact that to increase dependability of the circuit, the voltage divider R_3 and R_5, which is included, displaces the working points to the left portion of N-shaped characteristics, and to raise the working frequency of the circuit, a correction circuit R_2L, has been considered through which the discharge of capacity C_1 occurs.

The input signal is supplied to the triode base. The circuit operates steadily with an amplitude of the input signal which exceeds 2.5V. The circuit does not react on input signals of less than 1 volt.

The amplitude of the output impulse in a condition of no load is 20 - 25 volts. Figure 9 and 10 shows the relation of value of the output signal to resistive and capacitative loads. The load resistance of the circuit is 200-300 ohms when the maximum power of the impulse is 350 milliwatts. The input resistance during actual work is actually greater than the resistance of the base R_4= 3.9 K ohms. Coefficient of power amplification $K_r = R \frac{\text{output impulse}}{\text{input impulse}}$ in the considered circuit is equal to approximately 2000. The duration of the output impulse is determined basically by the value of the capacity C_1; in the

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given circuit it is equal to 0.3 - 0.5 microseconds. In the interval between impulses the voltages on the capacitor C_1 is restored by a constant of time which is determined basically by the resistance R_2. When the value R_2 is equal to 10 K Ohms and C_1 is equal to 200 micromicrofarads the working frequency reaches 200 kcs. When R_2 is 2.7 K Ohms and C_1 is 200 micromicrofarads, maximal working frequency reaches 500 KC.

Amplitude of Output, volts.

Load Resistance, ohms.

Fig. 9.

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Minimum value of the resistance R_2 depends on the nature of the triode; for the majority of triodes of one production lot the value is 2.7 K ohms; with further decrease of R_2 the validity of the sketch is reduced.

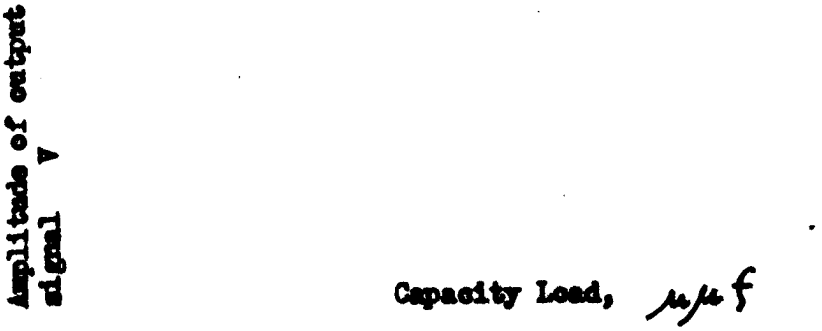

Fig. 10.

Tolerance for variance of feeding voltage is ± 15%. With a value of resistance R_2 - 2.7K ohms, 20 triodes out of 100 triodes of one production lot worked without change of parameters of the sketch; with an increase of the value of resistance R_2 to 10K ohms, 60 triodes worked without change.

4. Amplifier - The amplifier is collected on a semi-conducting triode, connected according to the sketch, with a grounded base (Fig. 11). The input resistance of the amplifier is determined by resistance R_1, which is intended

Fig. 11.

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for suppression of circuit oscillation, and the resistance of the emitter-base. The base of the amplifier is supplied with positive voltage, so as to block false signals. Point triodes of different types can be utilized in the amplifier. Variation of feeding voltage is permissible within the limits of ± 20%. The amplitude characteristic of the amplifier is given in Figure 12.

Amplitude of Input Signal, V.
Fig. 12.

5. Rectifiers:

a. Potential - impulse, parallel diode rectifier of coincidence. Controlling signals in this circuit (Figure 13) are the signals U_1 and U_2, the first of which represents the potential which is supplied by the main capacity of the dynamic trigger, and the second (value of which is not less than 5V) arrives as impulses from other logical elements. During absence of controlling signals, the potentials of points A and B are equalized by the entrance of a source of voltage E_2. So that the resistance of these

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points in relation to ground are identical, the resistance R_2 is introduced.

U Output

Fig. 13.

The number of turns on the transformer Tr_1 (40:40) is selected, considering compatability of resistances. Tolerance of feeding voltage should not exceed the limits of ± 15%.

b. Impulse parallel diode rectifier of coincidence. The circuit of this rectifier differs from the above described by the absence of a source of voltage E_2 and resistance R_2; and resistance R_1 is replaced by transformer Tr_1 (Fig. 14). These changes depend on the characteristic of the controlling signal U_1, which is the impulse signal, and arrives from similar logical elements, as does signal U_2 of the previous circuit. The tolerance is the same as above.

U Output

Fig. 14.

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c. The rectifier of incoincidence. In the circuit of the rectifier of incoincidence (Fig. 15) the controlling signal U_1 passes to the output only when the controlling signal U_2 is not present. During presence of the signal U_2 the positive signal U_1 is compensated by the negative signal U_2. If signal U_1 and U_2 are absent, then the diode $Д_2$ is closed, and diode $Д_1$ is open. The values of voltage of the feeding sources E_1 and E_2 are selected, considering the most favorable relation of true and false signals; the variation from its nominal value is tolerated within the limits ± 15%.

U Output

Fig. 15.

Oscillograms of the voltage, characterizing the work of the rectifier are given in Figure 16.

d. Triode rectifier of coincidence. The signal U_2 of the triode rectifier of coincidence (Figure 17) is taken off the storage capacity C_1 of the dynamic trigger. The signal U_1 enters from other logical elements. The voltage of the source of the base bias is somewhat less than the voltage sum of signals U_1 and U_2. The true signal appears in the output when two controlling signals are present.

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The circuit is critical to the value of controlling signals and to voltage changes of the base. The voltage change of the base is tolerated in the limits of ± 10%, the change of voltage E is tolerated in the limits of ± 20%.

Fig. 16. Oscillogram of voltage in the circuit of the rectifier of inconsistence.
a. - U_1, frequency 120 kilocycles, amplitude 5v.
б. - prevented input U_2, frequency 60 kilocycles, amplitude 8v - in output of the circuit, amplitude of working signal 4v.

Fig. 17.

The oscillograms of the voltage characterizing the works of the rectifier, are given in Figure 18.

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Fig. 18. Oscillograms of the voltage in the circuit of a triode rectifier of coincidence
а. - in secondary windings of input transformer, frequency 100 kilocycles, amplitude 5v.
б. - in capacity $C_1(U_2)$, amplitude 4v;
в. - in emitter of triode;
г. - in output, amplitude 5v.

II MAIN ASSEMBLIES OF THE MODEL

1. Shift Register.* - The shift register performs the following operations: receiving the signal, preservation of it, shift of the number to a desired number of networks and delivery of the number.

When reception of the number occurs, the code of the number in the form of short impulses passes on parallel connectives through the input rectifier B_1 to singular inputs of triggers T (Figure 19). For the reception of the number, the impulse of the number reception ($\pi ч$) is supplied to the rectifiers B_1. In view of the fact that during passing through the rectifier, the power of the impulse is reduced, the amplifiers $\forall_1$ and the shaping networks (ϕ_1) are mounted after the rectifiers.

*Shift Register. In the shift register, as in all following circuits, the described above elementary circuits are used.

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For realisation of the shift from the system of control, the shift impulse is supplied to the rectifiers B_2, in the phase coinciding with impulses ГИ . At the output of the rectifiers B_2 the impulses of transfer appear only in those networks when triggers are in position "1." Impulses of transfer further travel through the line of delay into the input of amplifiers $У_1$ of the following networks. During this, the impulse is delayed 1 microsecond, in other words twice the duration of the impulse. Within 0.5 microsecond after arrival of the shift impulse, the impulses Y"0" are supplied to all networks simultaneously, which puts triggers in position "0." The time of delay of impulse Y"0" is taken as equal to the duration of the shift impulse in order that the system of triggers in position "0" would not influence the work of the rectifiers B_2.

Fig. 19.

Rectifiers B_3, on the inputs of which the voltage from capacity of the triggers and impulses BY from the system of control are supplied, are performing the function of delivery of the number from the register.

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The register for 5 networks was assembled according to the above sketch, each network possessing 6 semiconducting triodes and 12 diodes. The register steadily worked with a change of frequency of shift impulses from 0 to 500 kilocycles. At this time the chain of shift was connected by supplying the transferring impulse from the output of last network to the input of the first.

Oscillograms in Figure 20 show the work of the register during shift of two codes.

Fig. 20. Oscillogram at the main capacity of the trigger of the 5th network during shift of the code.
a. - 00001, frequency ГЦ 500 kilocycles, amplitude 5v;
б. - 00111, frequency ГЦ 500 kilocycles, amplitude 5v.

2. Summator. - The summator performs the following operations: reception, addition and delivery of the numbers. All categories of the number are supplied to the input of the summator simultaneously. A skeleton of two networks of the summator is given in Figure 21.

Fig. 21.

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Let us suppose that we want to add two numbers 11+11 and that the code in the summator is 00. During reception of the first number on the input clamp "BX" of each network, a positive impulse is supplied, which places the trigger in position "1."

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Simultaneously, in every circuit, at one input of the rectifier of the discharge transfer B_1 appears an impulse, and a potential is produced at the second input, entering the cathode repeater from the capacity output of the trigger. The code impulses of the first digit cannot go through rectifier B_1 because before that the triggers were in position "0." In order that a false signal would not appear at the rectifier output during the proceeding process of the trigger, changes of potential in the basic capacity of the trigger are stopped at the line of delay ($Л3_1$) for a period 0.5 microseconds, equal to the length of the input impulse. The code impulses of the second digit are fed to the same inputs of the rectifiers B_1, but because the triggers are set in position "1" the impulses go through these rectifiers. The impulses of the discharge transfer are formed in this manner and enter the lines of delay ($Л3_2$) which have two leads. From lead 1, the impulse of transfer is sent to the zero input of the trigger and sets it into position "0." This impulse is stopped in the line of delay for a time which is equal to 0.5 microseconds, and after the impulse is completed in the unit input of the trigger, it goes to the zero input. From lead 2, the impulse of transfer is sent to the rectifier B_2 of the chain of the through transfer, which increases the quick operation of the summator. This impulse is stopped relative to the impulse of "0" also for the time of the length of the impulse (0.5 microseconds) and arrives at the rectifier of the through transfer, when the trigger is securely set at position "0" by the impulse of discharge transfer. From the end of the line of delay the impulse of the discharge transfer is sent to the unit input of the trigger of the following network. The overall

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delay of the impulse of the discharge transfer is equal to 1.5 microseconds.

The setting of the entire summator at position "0" is carried out by feeding the negative impulse to the line at position Y"0" Cm.

In order to send the digit from the summator to the line at B4Cm a positive impulse is sent, which opens outputs of rectifiers B_3 in those circuits in which the triggers are set at position "1."

All rectifiers in the summator are diodes. The rectifier of the through transfer is dependent upon the capacity of the output of the trigger, since the phase of the impulse of the through transfer can be changed within a wide range, and one cannot use a parallel diode circuit on two impulse inputs. Between the capacity output of the trigger and rectifier a cathode repeater is connected at tube 6Ж25, matching the low input impedance of the rectifier with the high (100 K ohm) output impedance of the capacity output of the trigger.

In the model, experimental research was conducted on a summator of five networks. The summator worked steadily performing the functions of storage during a frequency of digit feeding from 0-250 Kcs. The time of delay of impulse of the through transfer during the passage through one network amounted to 0.2 microseconds basically on account of the amplifier, the triode of which is normally closed in order to prevent false signals from passing from the rectifier of coincidence.

One stage of the summator has one electron tube, seven semi-conductor triodes and twenty-four diodes.

In Figure 22 is shown an oscillogram of the operation of the fifth stage of the summator at the time of feeding code 11111.

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Fig. 22. Oscillogram of the voltage at basic capacity of the trigger of the fifth stage of the summator.
Frequency (ГЦ) 500 KC. Amplitude of the signals 5 volts.

3. Counter - The circuit of the counter is analogous to the circuit of the through transfer of the summator. The first and second stages of the counter are shown in Figure 23. All the stages of the counter, except the first, are the same. Each stage of the counter has one electron tube 6Н25, four triodes and ten diodes.

The input impulses are sent simultaneously into the unit input of the trigger of the first stage and into the rectifier of the transfer of this same stage. The speed of calculation is determined by the basic amount of the delay of impulse of the transfer during the passage of it along the chain of transfers.

In the model, the four stage counter was working on a decoder, to which signals were sent from the impulse outputs of the trigger. These signals were pre-amplified in the shaping networks, from which were taken off two impulses of differing polarity.

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OUTPUT OUTPUT

TO SUBSEQUENT NETWORKS

INPUT

Fig. 23

The counter was working during changes of frequency of the input impulses from 0-500 KOS. Oscillograms of the work of the counter are given in Figure 24.

4. Decoder - The decoder converts parallel codes of double digits, being taken off from the output of the counter, into the time-sequence impulses on the outputs of the decoder. For one cycle of work of the counter, on all outputs of the decoder appears in sequence by one impulse.

The signals in view of the presence or absence of the series of impulses are sent through shaping network Φ to the diode matrix (Fig. 25) which represents a series of rectifiers of coincidence and in coincidence, having 5 inputs.

Figure 24. The oscillograms of voltages on the basic capacity of the triggers.
а. - first network; б. - second network
в. - third network; г. - fourth network

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NOTE: DIODES OF THE NETWORK ARE REPLACED BY DOTS

Fig. 25.

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From each shaping network is taken off positive and negative impulses. The negative impulses are fed to the suppressing inputs of the rectifiers of incoincidence, and for this reason their amplitude must be significantly greater than the amplitude of positive impulses.

The lowest set of diodes form the rectifiers of coincidence for the discharging of one impulse at the output of the shaping network when the counter is working at a lower frequency than the frequency of the following impulses ГИ . An amplifier and a shaping network are placed on each output of the decoder. On the base of the amplifier is supplied a cutoff voltage $E_б$ = 4 volts for the cutoff of false signals. In the matrix of the model, diodes ДГ4-8 were used, possessing low direct and high reverse impedance.

III MODEL OF ARITHMETICAL APPARATUS

In order to verify the above described connections in the overall complex, an experimental model of an arithmetical apparatus (AY) was constructed of five networks (Fig. 26). The model consisted of a register P_1, a register with shift P_2, a summator and a directing circuit AY - a four stage counter from which a shaping network with 15 outputs connected to respective directing lines AY.

TRIGGER IMPULSES

SUMMATOR SHAPING NETWORK COUNTER

Fig. 26.

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With the help of directing stages, the following operations could be performed automatically:

FIRST OPERATION

1. Y"0" AY;
2. reception of first digit on P_1;
3. reception of second digit on P_2;
4. transmission of the digit from P_1 to the summator;
5. add the digit in the summator to the digit in P_2;
6. transmit the result.

SECOND OPERATION

1. Y"0" AY;
2. reception of the digit on register P_2;
3. shift of the digit;
4. transmit the result.

Switching of operations is accomplished with the help of toggle switches.

A highly stable feeding voltage is not required. For example, a voltage of + 15 volts may be varied ± 8%. Variation in collector voltage is allowed within ± 10%.

About 150 point triodes were tested in the model in which the total dark current reached 300 milliamps; therefore, voltage dividers consisting of low resistance were used. Thus, economy of point triodes in the circuit is somewhat less than expected if considering only the power of distribution on the collector.

The impulses ГИ are formed in the circuit at tube 6П9 by the transformers output. The coefficient of transformation was large (50:1) for best

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lead matching. One such shaping network worked on all triggers of the model. Impulse modulation at the output was insignificant. Tests of the model showed that almost all of the units worked safely under real loads. Only the successive triode rectifiers whose work significantly depended upon the feeding voltage and amplitude of the input impulse did not perform safely. The parallel diode rectifiers worked significantly better; however, even in this case, the impulse amplitude depends on the input impulse amplitude. In addition, parallel diode rectifiers have low powered output signals.

The triodes did not work beyond established limits. In the shaping network U_k = -30 volts, I_k max = 20 milliamps, $P_k \leq 50$ milliwatts and in the remaining networks U_k = -20 volts, I_k max = 40 milliamps (at impulse), P_k max $\leq$ 50 milliwatts. The work of the network is improved by an increase of frequency limit, by amplification factor according to current, and by reduction collector dark current: and improved in the trigger also by an increase in base triode resistance. Input triode characteristics also are very important in the impulse shaping network.

In conclusion, it must be mentioned that confirmation by experiment allows the conclusion that it is possible to construct on the basis of the above experimental circuits an arithmetical apparatus of parallel action having 40 paired networks which use about 900 semi-conducting triodes and 40 electron tubes. The power used (without electron tubes) would be in the order of 150 watts. Pure addition time (during operation with fixed comma*), not considering the time for transmission of the digit to register is determined to be about 10 microseconds.

* TRANSLATOR'S NOTE - POSSIBLY "DECIMAL"

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